USAFETAC/PR-93/006

UPPER-AIR QUALITY CONTROL

A COMPARISON STUDY

By

Captain David J. Speltz

DECEMBER 1993

USAFETAC

Past Weather - Our Future

USAF
ENVIRONMENTAL TECHNICAL
APPLICATIONS CENTER
859 Buchanan Street
Scott Air Force Base, Illinois 62225-5116

REVIEW AND APPROVAL STATEMENT

AWS/PR-93/006, *Upper Air Quality Control, A Comparison Study,* December 1993, has been reviewed and is approved for public release. There is no objection to unlimited distribution of this document to the public at large, or by the Defense Technical Information Center (DTIC) to the National Technical Information Service (NTIS).

LAURALEEN O'CONNOR, Maj, USAF
Chief, Simulations and Techniques Branch

DAVID J. SPELTZ, Capt, USAF
Author

FOR THE COMMANDER

CAROL L. WEAVER, PhD
Chief Scientist
31 January 1994

REPORT DOCUMENTATION PAGE

2. Report Date: December 1993

3. Report Type: Project Report

4. Title: Upper-Air Quality Control, A Comparison Study

6. Author: Captain David J. Speltz

7. Performing Organization Name and Address: United States Air Force Environmental Technical Applications Center (USAFETAC/SYT), 859 Buchanan Street, Scott AFB IL 62225-5116

8. Performing Organization Report Number: USAFETAC/PR—93/006

12. Distribution/Availability Statement: Approved for public release; distribution is unlimited.

13. Abstract: This study compares the output of the upper-air quality control (QC) methods used by the Air Force Global Weather Central (AFGWC) with those of the National Meteorological Center (NMC). AFGWC uses the New Upper-Air Validator (NUAV), while NMC uses the Complex QC procedure for Rawinsonde Heights and Temperations (CQCHT). This study identifies advantages, disadvantages, and added value of each QC scheme.

14. Subject Terms: WEATHER, UPPER-AIR OBSERVATIONS, RAWINSONDE, SOUNDINGS, QUALITY CONTROL, COMPARISONS, METHODS, ERRORS, ALGORITHMS, HEIGHT, TEMPERATURE, THICKNESS, HYDROSTATIC CHECKS, RAOB, QUALITY CONTROL OF HEIGHTS AND TEMPERATURES, CQCHT, NUAV, HYDROSTATIC CHECK.

15. Number of Pages: 30

17. Security Classification of Report: Unclassified

18. Security Classification of this Page: Unclassified

19. Security Classification of Abstract: Unclassified

20. Limitation of Abstract: UL

Standard Form 298

PREFACE

In February 1992, the Current Operations Branch of Air Force Global Weather Central (AFGWC/DOO) requested a comparison study of upper-air quality control (QC) methods used by AFGWC and the National Meteorological Center (NMC). The request stemmed from an offer by NMC to provide rawinsonde observations (raobs), quality-controlled by their algorithm, to AFGWC. Since AFGWC now QCs and corrects its own raobs, the advantages, disadvantages, differences, and any added value of each correction scheme had to be determined before accepting the offer. The Simulations and Techniques Branch (SYT) at USAFETAC completed the comparison under project number 920313. The author/analyst was Capt David J. Speltz, who wishes to thank Dr. William G. Collins of NMC for the wealth of information he provided on the CQCHT algorithm, as well as for output from the program.

CONTENTS

TABLES

1. INTRODUCTION

1.1 Purpose of Study. This study compares the output of the upper-air quality control (QC) methods used by the Air Force Global Weather Central (AFGWC) with those of the National Meteorological Center (NMC). For its upper-air QC, AFGWC uses the New Upper-Air Validator (NUAV) which became operational on 22 December 1986 (Zamiska, 1990). NMC uses the Complex QC procedure for Rawinsonde Heights and Temperatures (CQCHT) algorithm, which has been operational since November 1991 (Collins, 1991). This study identifies advantages, disadvantages, and any added value of each correction scheme.

1.2 Data Used. At the end of each month summaries of QC results were produced for both NUAV and CQCHT. NUAV results, stored in the DATSAV2 data format, were obtained through the Climatic Operations Branch (GCO) of OL-A, USAFETAC, in Asheville, NC. The CQCHT data was provided by Dr. William G. Collins of NMC in Washington, DC. Data for the months of July and November was used for this study.

1.3 Methodology. Samples of observations that had been QC'ed by both algorithms were selected at random. Each error in the samples was examined manually and categorized based on their characteristics. Conclusions were drawn from the number of observations in each category. Bulk statistics describing the output for each algorithm were also examined. Finally, the advantages and disadvantages of each algorithm were compared subjectively to determine which was more effective.

1.4 Difficulties. Although both QC algorithms try to achieve the same thing (to correct or at least detect incorrect observations), differences in the methods used by each complicated comparisons. For example, since NMC uses a more stringent cutoff time than AFGWC, more observations get into the AFGWC database than into NMC's. This leads to problems in determining whethr CQCHT missed an obvious error or just simply never checked the station in question at all. The CQCHT output provides much more information about the *nature* of the error than NUAV; this NUAV shortfall often makes errors detected by NUAV difficult to evaluate. These were just a few of the many problems encountered in attempting a comparison of this type.

1.5 Results. A careful search of the literature, along with comparisons of 2 months of data processed by NUAV and CQCHT, show CQCHT to be the better algorithm. Not only does it detect more errors, but it generally makes more reasonable corrections as well.

2. COMPARING QUALITY CONTROL ALGORITHMS

2.1 New Upper-Air Validator (NUAV). Automated QC of weather data has been a necessity since the beginning of the age of numerical weather prediction in the mid-1950s. Automated QC methods have come a long way since then, and they continue to be improved every year by the various numerical weather prediction centers. AFGWC recognized the need to update their QC system in the late 1970s and began work on the upgrade in 1982. Among the many problems with the old algorithm were a lack of sensitivity in the height and temperature checks, misinterpreted thickness checks, and errors in processing and storing data. NUAV, which became operational on 22 December 1986, solved many of the problems (Zamiska, 1990).

2.2 Complex QC Procedure for Rawinsonde Heights and Temperatures (CQCHT). The National Meteorological Center (NMC) began designing a new QC system from scratch in 1988 (Gandin and Collins, 1992). This system, which became operational in early 1989, was called Comprehensive Hydrostatic Quality Control (CHQC). It comprised two major parts: (1) The statistical checks that produce numerical residuals and (2) the Decision Making Algorithm (DMA) that analyzes the residuals before reaching a decision. The DMA tries to determine the origin of each error and correct it rather than simply rejecting it.

CHQC was the first QC algorithm in this country to apply this approach (Gandin and Collins, 1992). An advanced method (called "Complex Quality Control," or "CQC") has been in use at the Hydrometeorological Center in Moscow since 1979 (Gandin, 1988). Dr. Lev Gandin, formerly of the Hydrometeorological Center and now at NMC, was instrumental in bringing the CQC concept to the United States.

CQCHT replaced CHQC in November 1991. CQCHT is similar to CHQC, but it includes several additional statistical checks and uses a more advanced DMA. These upgrades allow CQCHT to make more corrections automatically. Table 1 shows the types of errors that CQCHT can automatically detect and correct. In contrast, CHQC only performed corrections on Types 1 and 2 and 7 through 10. Not only are more corrections possible, but a higher degree of confidence is placed in each correction.

Table 1. Errors that CQCHT automatically detects and corrects (Gandin and Collins, 1992).

Type	Error
1	Large height error at an intermediate level (not the highest or lowest)
2	Large temperature error at an intermediate level
3	Errors in height and temperature at the same level
4	Error(s) in height and/or temperature at the lowest reported level
5	Error in either height or temperature at the highest level, or error in both
6	Computational error in layer thickness
7	Errors in heights of two adjacent layers
8	Errors in temperatures of two adjacent layers
9	Adjacent errors in height below and temperature above
10	Adjacent errors in temperature below and height above
11	Medium-size height error at an intermediate level
13	Data hole including upper Part A levels
14	Data hole different from type 13 error
22	Medium-size temperature error at an intermediate level
100	Surface pressure or station elevation error (communications-related)
101	Height error in lowest level when its temperature is missing
102	Undetermined error in the lowest level (no correction made)
106	Observational error in the surface pressure
116	Computational error in height of the lowest level

2.3 Quality-Control Check Summary. A summary of major checks on upper-air data accuracy used by NUAV and CQCHT follows.

2.3.1 Hydrostatic Check. This check, used in both algorithms, is the most powerful.The hydrostatic check is based on the redundancy of reported heights and temperatures in the rawinsonde data. Rawinsondes do not measure heights directly; heights are calculated from measured temperatures and pressures using the hydrostatic equation. The thickness of each layer may be calculated by either determining the difference in heights of the boundaries, or by using the measured temperatures and pressures in the hydrostatic equation. The difference between these two thickness values is called the "hydrostatic residual," which should be zero or near-zero since the hydrostatic equation was used to compute the heights in the first place. If the values do not agree hydrostatically, there is an error in one of the following areas:

- Computation at the observation location
- Data entry (e.g., digits transposed)
- Data transfer
- Decoding of the data

Both NUAV and CQCHT use the magnitude of the hydrostatic residuals to detect errors, as well as to help determine what corrections to make. Observational errors, like those resulting from a broken sensor, are NOT detected by this method.

2.3.2 Increment Check. An "increment" is defined as the difference between the reported value and its forecast "first guess." The first guess is a 6-hour forecast from a numerical model. The increment check is performed on height and temperature; some form of it is used by both methods. CQCHT uses the value of the increment in statistical checks, while NUAV flags suspected observations in which increments exceed predetermined numerical limits. It's important to note the distinction between the quantitative way in which CQCHT uses this check and the qualitative flagging performed by NUAV. The value of the increment check lies in its ability to provide additional information to confirm, reject, or refine the findings of the hydrostatic check.

2.3.3 Horizontal Check. This check uses the increments of the four nearest stations, each in a different quadrant. From these four increments the value of the point in question is interpolated. If the interpolated increment differs greatly from the calculated increment, then the data (temperature or height) is considered suspect. Only NMC's CQCHT employs this check.

2.3.4 Vertical Check. This check is performed in a manner similar to the horizontal check, but now the size of the vertical residual is examined. The vertical residual is the difference between the increment (height or temperature) at the level in question and the increment value interpolated from the mandatory levels above and below this level. NUAV does not use this form of vertical check, but it does employ a temperature validation using lapse rates. If the lapse rate for a particular layer of the sounding is outside predetermined limits set by OL-A, USAFETAC, steps are taken to reject or correct the temperature(s) causing the problem. CQCHT also examines lapse rates to ensure that temperature corrections are not excessive.

2.3.5 Baseline Check. This is essentially a hydrostatic check for the layer between the surface and the lowest reported mandatory level. The thickness between the two lowest mandatory levels is used to compute an average temperature from which the temperature profile of the lowest layer is computed by extrapolating downward to the surface pressure using the standard lapse rate (6.5° C/km). These assumptions are then used to solve for station elevation, which is compared to the *official* station elevation. Large discrepancies between the two values indicate 1,000-mb height errors or an incorrect "official" station elevation (Collins and Gandin, 1990). Both algorithms use some form of this check.

2.3.6 Gross Error Check. NUAV uses a list of maximum and minimum values of height and temperature at mandatory pressure levels to detect values that should be suspected or rejected. This is one form of the wide plausibility check, which is relatively simple to design and apply, but the CQC method gets the same results and much more. For these reasons Dr. Gandin considers it "hardly worthwhile to use any check of plausibility" (Gandin, 1988). In addition, gross error checks are not capable of making confident corrections when used alone. Despite these limitations, NUAV is able to detect numerous errors with this check. Since temperature errors often result from switched signs, the sign is switched for any temperature within 10° C of zero and the new temperature is checked again. Flags are set when a value is suspect or rejected. These flags are later used to determine the overall quality of the sounding and whether it should be used or not.

2.4 Discussion of Comparisons. Although both algorithms use the powerful hydrostatic check, the addition of increment, horizontal, and vertical checks to CQCHT allow it to detect (and often correct) additional errors. The added value of these additional checks is illustrated in Table 2. This data, from the June 1992 CQCHT summary, shows stations suspected of Type 22 errors (medium-sized temperature errors).

Table 2. CQCHT increment, horizontal, and vertical checks of temperature (T). June 1992 results are shown for two stations. Hydrostatic residuals are for the layers above and below the layer in question.

Station	Level (mb)	Old T (°C)	New T (°C)	Hydrostatic residuals (° C)		Increment (°C)	Residuals (°C)	
				Above	Below		Horiz	Vert
Hailar, China	200	-50.1	-57.1	-4.2	-1.5	10.6	10.0	9.8
Kupung, Indonesia	50	-68.1	NO CHG	4.3	5.6	1.5	1.4	1.9

Both stations are suspect due to the large hydrostatic residuals in the layers above and below the level in question, but in the case of station Kupung (El Tari), Indonesia, this suspicion is not confirmed by the other checks. Although Kupung had larger hydrostatic residuals than Hailar, the small size of the other checks showed that a temperature error was very unlikely. Note the large size of the increment and spatial residuals for Hailar; these confirm the error. NUAV would not have been able to make a confident determination in this case.

As discussed earlier, CQCHT uses the baseline check, in combination with others, to detect and correct additional errors. Error types over 100 (Table 1) are those detected with the aid of the baseline check. NUAV can correct some Type 100 errors (e.g., surface pressure) by switching digits or adding/subtracting 100 to obtain a better pressure.

The previous version of the NMC QC algorithm (CHQC) implemented in late 1988 used only a hydrostatic check somewhat similar to the one NUAV uses. Dr. William Collins, who works with QC algorithms at NMC, expressed the following opinion about CHQC (Collins and Gandin, 1990): "It would hardly be possible to substantially improve the CHQC version now in operational use at NMC. Further progress may be achieved only after some other statistical checks have been developed and added to the hydrostatic one." This goal was accomplished when CQCHT became operational in November of 1991.

Because NUAV also lacks statistical checks, its performance is probably no better than the recently replaced CHQC. The addition of other checks has indeed improved the performance of the NMC algorithm. A study of 15 observation periods in December 1991 found that CQCHT detected an average of 26 more errors (81 versus 55) and confidently corrected twice as many errors (58 versus 24) during each period as CHQC (Morone et al., 1992). It appears likely that NUAV would perform no better than CHQC since both lack the spatial and quantitative increment checks to help make their determinations.

The strength of CQCHT lies in the way the results of the various checks are expressed and interpreted (Gandin and Collins, 1992). The results of each check are expressed quantitatively in the form of residuals, rather than with flags like NUAV uses. The DMA analyzes the magnitude and pattern of these residuals before making a quality control decision. This allows the DMA to determine the origin of the error in most cases and to correct the error whenever possible. CQCHT produces a printout of each error with the corrections, hydrostatic residuals, increments, and spatial residuals. This makes the confirmation of errors much simpler than with NUAV, which only produces the old and new values, a validation flag showing which check(s) the observation failed, and an observation quality indicator. In nearly 5 years separating the start dates of CQCHT and NUAV, there have clearly been a number of advances in quality controlling weather data

A final example of the value of CQCHT's additional checks is in the area of observational errors, which usually result from faulty temperature sensors. Since the heights of the mandatory levels are computed from the temperature profile (faulty in this case) using the hydrostatic equation, and not from independent height measurements, the hydrostatic check will not detect observational errors. The temperature errors as well as the resulting height errors will be obvious upon examining the increment and spatial check results. Although CQCHT cannot correct observational errors, it can reject these observations and prevent faulty data from entering the database.

Table 3 shows an instance of an observational error that occurred on 14 July 1992 at Great Falls, Montana. Only the horizontal residuals are shown because the increments and vertical residuals show essentially the same effect. Note the small magnitude of the hydrostatic temperature and height residuals. The horizontal temperature residuals are large and fairly constant above 400 mb. The persistent positive temperature error leads to dramatic height errors as well; note how the height residuals steadily increase with height as the errors are compounded with each level. NUAV did not find any errors except at the 100-mb level, where the temperature exceeded the NUAV gross error check REJECT limit shown in the last column of Table 3.

All the other heights and temperatures exceeded the NUAV gross error check SUSPECT limits (not shown), but there was apparently not enough supporting evidence available for these values to be corrected or rejected.

The case illustrated in Table 3 is not a rare event; it is fairly common and has a strong effect on total error counts. During the months of June-December (excluding September) 1992, an average of 41.8 percent of the errors detected by CQCHT were observational errors.

Table 3. CQCHT detection of observational temperature (T) and height (H) errors. The case shown is for Great Falls, Montana, on 14 July 1992. Hydrostatic residuals are for the layers above and below the layer in question.

Level (mb)	Original Values		Hydrostatic Residuals				Horizontal Residuals		NUAV High Reject Limits	
	T (° C)	H (m)	T (°C)		H (m)		T (°C)	H (m)	T (° C)	H (m)
			Abv	Blo	Abv	Blo				
500	3.0	5,930	0.8	0.7	8	7	13.4	187	17.0	6,300
400	-3.7	7,720	0.2	o.8	2	8	19.1	297	5.0	8,100
300	-13.5	9,950	0.0	0.2	0	2	24.7	478	-5.0	10,300
250	-19.3	11,320	0.6	0.0	6	0	28.9	620	-9.0	11,600
200	-26.6	12,960	-1.0	0.6	-10	6	31.6	833	-13.0	13,300
150	-27.8	15,020	0.4	-1.0	4	-10	27.6	1,069	-20.0	15,300
100	-27.1	17,950	-0.3	0.4	-3	4	29.4	1,416	-28.0	18,000

3. METHODOLOGY

3.1 Dealing with Output Differences. In order to conduct a valid comparison of the algorithms, the many differences in the output produced by each must be accounted for, if possible. These are the major differences:

• The CQCHT data summary contains much more information about the error, the correction made, and why the observation was considered suspect in the first place.

• AFGWC generally uses a more liberal data cutoff time, thereby allowing more data to be processed by NUAV than by CQCHT. Part C of the sounding (mandatory levels 70 mb and above) is sent later than part A (mandatory levels 1,000-100 mb). Therefore, on some occasions only part A makes it into the CQCHT database, while NUAV processes the entire sounding.

• The confidence placed in each correction is expressed differently by each of the two methods. More will be said on this later.

3.2 Data Used. Summaries of monthly QC data for July and November of 1992 were obtained from OL-A, USAFETAC, and NMC. Only mandatory level data (1,000, 850, 700, 500, 400, 300, 250, 200, 150, 100, 70, 50, 30, 20, and 10 mb) was used. Only height and temperature were examined. AFGWC and NMC both QC significant level data, wind speed and direction, and dew point (density), but QC in these areas is much less advanced. Since significant level data does not include height information, the redundancy used by the hydrostatic equation to find errors is not available. Lack of a strong constraint like the hydrostatic equation severely limits QC of wind and moisture data as well.

Early in this project it became clear that apparent lapses in QC were due to the fact that somewhat different datasets were being processed by each algorithm. CQCHT did not correct a 500-mb height from 1,460 to 5,460 meters as NUAV did simply because that observation did not reach NMC in time to be in the database. To solve this problem, only stations processed by both algorithms on a certain date and time were used. It was also necessary for both stations to have Part C of the sounding if errors were suspected above 100 mb.

In addition, there were some problems in the DATSAV2 datasets used in this study. The most common problem was the occurrence of negative height values in the rejected data section of the output. Negative heights at the 1,000-mb level occur at low elevation stations, but values between -10,000 and -70,000 meters are commonly reported at all mandatory levels. During the months examined, 45 percent of the rejected height values are negative, making it difficult to determine the validity of the correction in many cases. Height values greater than -1,100 meters (the NUAV cutoff value) at 1,000 mb were considered acceptable, but negative values at other levels were rejected.

3.3 Comparison Methods. There are several ways to compare the error detection capabilities of NUAV and CQCHT. Each has strengths and weaknesses, and each helps highlight differences and similarities. In the first method, a direct comparison is made between stations with errors picked at random. Each case is examined manually and placed in a category. Each error is either detected by both algorithms, only detected by NUAV, or only detected by CQCHT. These categories are broken down further, as shown here:

• *Both algorithms detected error:*
  - B1 - CQCHT correction better
  - B2 - NUAV correction better
  - B3 - Both corrections good

• *Only CQCHT detected error:*
  - C1 Correction good
  - C2 Correction bad
  - C3 Error detected, but correction not possible

- *Only NUAV detected error*:
  - N1 Correction good
  - N2 Correction bad
  - N3 Undetermined
  - N4 Correction unnecessary

Each of these categories, and how the proper one is chosen, is discussed next.

B1—Both detected, CQCHT better. The results of the hydrostatic check and the increment, horizontal, and vertical residuals make determining the validity of CQCHT corrections relatively simple in most cases. If the correction is strongly supported by the various checks, then it is usually placed in this category. Another piece of supporting evidence is the making of a simple correction. Most errors are due to mistyping a digit, transposing digits, or a sign error in the temperature. It takes a simple correction to fix one of these errors. But how is the category determined if CQCHT makes a correction that is strongly supported by all the available evidence, and if NUAV makes a correction very close in magnitude? Based on raob accuracy studies (Ahnert, 1991), 2.0 mb is a good average value for the root mean square (rms) of the pressure differences between various raob sensors. Using a 2.0-mb error and height and temperature values from the standard atmosphere in the hypsometric equation leads to height differences of about 0.5 percent. If the NUAV height value is within 0.5 percent of the corrected (good) CQCHT height value, both corrections are considered good. The value used for temperatures is 1.0° C. Table 4, with data from Alta Floresta, Brazil, on 29 July 1993, illustrates a case of a correction being placed in this category.

Table 4. B1–Both algorithms correct error, but CQCHT result better. Example from 29 July 1993, Alta Floresta, Brazil.

Method	Level (mb)	Old H (m)	New H (m)	Change (m)	Hydrostatic Residuals (m)				Increment (m)	Residuals (m)	
					Before		After			Horiz	Vert
					Abv	Blo	Abv	Blo			
NUAV	500	8,880	5,816	-3,064	------	------	------	------	-------	-------	-------
CQCHT	500	8,880	5,880	-3,000	2,996	3,032	3	32	3,025	3,023	3,023

The hydrostatic residuals provide the strongest support for this correction by CQCHT. The hydrostatic residual for the layer below (700-500 mb) is +3,032 meters and -2,996 meters for the layer above (500-400 mb), consistent with the 500-mb height being about 3,000 meters too high. After the correction is made, these residuals (32 and 3 meters) essentially disappear. The other checks also suggest a positive error of roughly 3,000 meters. CQCHT chooses the simplest correction, provided it reduces the residuals the most. The NUAV correction is certainly better than keeping the original value, but the CQCHT data does not support a change of 3,064 meters. In addition, the NUAV correction is not within 0.5 percent of the strongly supported CQCHT correction.

In many cases CQCHT does not correct the observation, but merely flags it as incorrect (see Category C3). In these cases the statistical evidence is not strong enough to make a confident correction, but the CQCHT output does provide enough information to determine a *likely* correction. In this situation, the observation is usually placed in the "both corrections good" category, provided the NUAV correction is supported by the CQCHT output and nearby soundings.

B2--Both detected, NUAV better. Unfortunately, very little evidence is available to support the NUAV correction over the CQCHT correction. Without the extensive list of results from the various checks like CQCHT produces, there is usually no reason to consider the NUAV result better. Only a gross error by CQCHT (like correcting a 500-mb height from 5,560 to 1,560 meters) coupled with a reasonable NUAV correction would cause the NUAV result to be declared better. Such cases may occur, but they are very infrequent.

B3--Both detected, both corrections good. As explained earlier, if the CQCHT correction is considered good and the NUAV value is within 0.5 percent of the corrected height or 1° C of the corrected temperature value, both corrections are considered good. The CQCHT value is used as the basis for determining whether the correction is good or not good simply because so little information is provided with the NUAV corrections. An example of this type of correction is shown in Table 5 (Harare, Zimbabwe, 23 July 1992). All the evidence suggests a positive error of about 2,000 meters. The CQCHT correction is further supported by the simple one-digit change. The correction by NUAV is certainly not simple, but since it only differs from the CQCHT value by 0.3 percent, it is also considered a good correction.

Table 5. B3--Both algorithms make good corrections. Case from 23 July 1992, Harare, Zimbabwe.

Method	Level (mb)	Old H (m)	New H (m)	Change (m)	Hydrostatic Residuals (m)				Increment (m)	Residuals (m)	
					Before		After			Horiz	Vert
					Abv	Blo	Abv	Blo			
NUAV	200	14,440	12,403	-2,037	-------	-------	-------	-------	-------	-------	-------
CQCHT	200	14,440	12,440	-2,000	-1,999	1,994	0	-5	2,017	2,007	2,000

C1--CQCHT only, correction good. The techniques already discussed are also used to place corrections in this category.

C2--CQCHT only, correction bad. There is rarely any evidence to suggest that the correction is bad. If the evidence suggesting the presence of an error is not very strong, a correction is not made and the observation is flagged for further analysis (see C3 below). Because only cases with the strongest supporting evidence are corrected, the chances of a poor correction being found is very low.

C3--CQCHT only, error detected, but not corrected. Many (35 percent is typical) of the suspected errors are not correctable. These observations are put into one of two error groups. Error type 3 observations are probably bad and are passed to a specialist who either rejects or retains the value. Error type 4 observations are definitely bad and are automatically rejected. The decisions of the NMC specialist are not included in the CQCHT output.

N1--NUAV only, correction good. Errors placed in this category are essentially CQCHT "misses." Little evidence is available to help determine whether the correction is good or not. Nearby soundings are examined for any large disparities with the suspect value. Reasonable changes in gross errors are generally considered to be good corrections.

Table 6. N2–Poor corrections made by NUAV. Case from Frobisher, Canada, 11 July 1992.

Method	Level (mb)	Old H (m)	New H (m)	Change (m)	Hydrostatic Residuals (m)				Increment (m)	Residuals (m)	
					Before		After			Horiz	Vert
					Abv	Blo	Abv	Blo			
NUAV	300	8,940	9,020	+80	----	----	----	----	------	------	------
NUAV	250	10,130	10,210	+80	----	----	----	----	------	------	------
CQCHT	200	11,670	11,600	-70	1	78	----	----	37	30	50
CQCHT	150	13,510	13,580	-70	-1	1	----	----	26	24	3
CQCHT	100	16,280	16,210	-70	0	-1	----	----	25	21	7

N2--NUAV only, correction bad. The same factors are used as in determining if the correction is good. Sometimes an error may have been detected by CQCHT at the level above or below the level NUAV suspects. If the CQCHT correction appears to be good, this fact may rule out the NUAV correction. Table 6 shows an example of this from Frobisher, Canada, on 11 July 1992. The key level to look at here is 200 mb, where CQCHT has made a minus 70-meter correction in the height. This is a Type 6 error (see Table 1) or a computational error in thickness. The hydrostatic residual for the layer below (250-200 mb) is plus 78 meters, while the layer above (200-150 mb) has essentially no residual.

The other CQCHT checks also suggest that the 200-mb height is too large. Note, for example, the relatively large, positive increments and horizontal residuals at 200, 150, and 100 mb. A large vertical residual (50 meters) occurs at 200 mb because the error is probably between the levels used to compute the residuals (250 and 150 mb). In contrast, the vertical residuals at 150 and 100 mb are probably small because errors of identical magnitude occur at the neighboring levels. This is strong evidence that the 200-mb level is too high, not that the 250-mb level is too low, as NUAV has found. Note how the 70-meter computational error at 200 mb also affects every layer above it. These layers are in hydrostatic balance (extremely small hydrostatic residuals); they probably looked fine to NUAV, but the increments and spatial checks provided CQCHT with enough additional evidence to detect the error.

N3--NUAV only, undetermined result. In most of the cases, there is no evidence either for or against the NUAV correction. The most common cause for this lack of evidence is missing or incorrect original data values. As mentioned earlier, negative rejected height values are a common problem. Occasionally, more than one original value is listed, also making the error difficult to evaluate. In certain cases, NUAV generates mandatory level data for missing levels. CQCHT never "creates" missing data in this manner. This is a difficult situation to classify since the creation of data is not really a QC function. Because this situation is relatively uncommon and the "corrections" generally do not result in large errors, these cases are considered undetermined.

N4--NUAV only, unnecessary correction. Some of the NUAV corrections are unusually small; a 1° C temperature correction or a 5-meter height change is hard to justify. These corrections would probably cause little or no harm in the operational database, and there is no reason for making them. Height corrections for 20 meters or less and temperature corrections for 2° C or less are placed in this category.

3.4. Other Comparison Methods. A less direct method of comparison is to simply count the total number of errors detected by each algorithm.

As discussed earlier, some of the differences in error counts may be due to the fact that slightly different data is processed by each algorithm. Another difficulty is that NUAV does not declare some observations to be in error but not correctable as CQCHT does. In addition, negative rejected height values in the NUAV data make some observations difficult to categorize.

A final way to compare algorithms is to count the number of stations with errors. It is important to make the distinction between the *number of errors* and the *number of stations with errors*. Since a particular station may have errors at several different levels, the number of errors is greater than the number of stations with errors. Since it's difficult to determine how best to summarize errors, statistics on both counting methods are presented. The occurrence of a computational error in layer thickness provides a good example of how errors can be counted differently. A single error in computing the 850-700 mb thickness leads to identical height errors at every level above 850 mb. Cases of 10 height corrections due to a single computational error at a station are not uncommon.

4. RESULTS

4.1 Direct Comparison. A dataset containing only stations/dates in which both algorithms detected errors was created (see Section 3.2). From this dataset, 25 stations from both months were picked at random and the results from NUAV and CQCHT were compared manually. Each error was evaluated and placed in one of the categories discussed in Section 3.3. Since each station may have had more than one error on a particular date and time, the total number of errors was greater than 50. Table 7 shows the results of this comparison for the months of July and November 1992. An average of only 25.6 percent of the errors was detected by both algorithms. Of these stations, 80.5 percent of the corrections were performed equally well by each algorithm. Most of the errors in this group were very large and resulted from switched temperature signs and mistyped height values.

Table 7. Direct comparison of errors at 50 randomly selected stations.

Category	July	November	Average	Percent of Total
Both picked, CQCHT better (B1)	3	4	3.5	5.0
Both picked, NUAV better (B2)	0	0	0	0.0
Both picked, BOTH good (B3)	16	13	14.5	20.6
CQCHT only, good corr. (C1)	12	24	18.0	25.5
CQCHT only, bad corr. (C2)	0	0	0	0.0
CQCHT only, NO corr. (C3)	19	14	18.0	23.4
NUAV only, good corr. (N1)	4	9	6.5	9.2
NUAV only, bad corr. (N2)	2	1	1.5	2.1
NUAV only, undetermined (N3)	2	9	5.5	7.8
NUAV only, unnecessary (N4)	3	6	4.5	6.4

Cases in which both algorithms detected an error at the same date, time, station, and level can be compared to assure that identical data was processed. For this reason, errors belonging in the "both" group are studied in more detail. A random sample of 100 of these cases was chosen from each month and placed in the categories shown in Table 8, on the next page. The same techniques discussed previously are used to categorize the data. As in Table 7, not enough information is available with the NUAV errors to place errors in a "NUAV better" category. If the corrections made are different and the various CQCHT checks provide strong support, it is assumed that the CQCHT correction is better.

Table 8. Direct comparison of errors detected by both algorithms.

Category	July	November	Combined
Temperature, Both Good	44	54	98 (49.0%)
Temperature, CQCHT better	20	16	36 (18.0%)
Total Temperature errors	64	70	134 (67.0%)
Height, Both Good	21	12	33 (16.5%)
Height, CQCHT better	15	18	33 (16.5%)
Total Height errors	36	30	66 (33.0%)
All errors, both Good	65	66	131 (65.5%)
All errors, CQCHT better	35	34	69 (34.5%)

Of the 200 errors examined, 65.5 percent were well corrected by both algorithms. Most of these errors were quite large and easily detected by the hydrostatic check employed by both algorithms. The remaining 34.5 percent of the errors were corrected more accurately by CQCHT, but the difference was generally not very large. These percentages suggest that the hydrostatic check used by NUAV generally performs as intended.

The additional statistical checks performed by CQCHT allow it to fine-tune its corrections to a higher level of accuracy. Temperature errors accounted for 67 percent of those examined; 98 of 134 (73.1%) were corrected equally well by both algorithms. In comparison, only 50 percent of the height errors were corrected equally well by both. This is probably because most of the temperature errors are fixed simply by switching the sign, while height errors are more complex. Another cause of the difference is the criteria used to determine when NUAV and CQCHT height and temperature values are essentially equal. This comparison completely ignores the errors detected by one algorithm because of its inherent strengths, as well as the errors, and missed by the other because of certain weaknesses.

Although simply switching the sign of the temperature corrects many errors, this is not always the answer. The corrections made by NUAV on the 30 July/00Z data from Karachi, Pakistan, (shown in Table 9) illustrate the problems that can result if this approach is not used carefully. For unknown reasons, NUAV reverses the signs of the temperatures at 850 and 700 mb, leading to improbably cold readings for Karachi (24° 54'N, elevation: 24 meters) in July. Table 9 provides several other examples, Sprinagar, Iran (681 NM from Karachi) reported a 700-mb temperature of plus 13.6° C, providing support for not changing the original temperature. Not only are the corrected temperatures too low in this case, but the resulting vertical temperature profile is very unlikely. Although the improper sign on a temperature is a common error detected frequently by both algorithms, NUAV seems to make improper corrections fairly often. The large errors that result would certainly cause the sounding to be out of hydrostatic balance, but apparently the NUAV hydrostatic check still cannot detect the error. This type of error could not be detected in the CQCHT output. It's important to note that most of these errors are much smaller, usually less than 10° C.

Table 9. Erroneous NUAV temperature corrections.

Block Station Number	Date	Level (mb)	Old T (°C)	New T (° C)	
				NUAV	CQCHT
Karachi, Pakistan	30 Jul/00Z	850	+25.4	-25.4	No Change
		700	+13.0	-13.0	No Change
Bangalore, India	14 Jul/00Z	500	-51.5	+51.5	-1.5
Makung, Taiwan	22 Jul/12Z	300	-32.1	No Change	No change
		250	-41.5	No Change	No Change
		200	+31.0	-31.0	-51.5
		150	-63.9	No Change	No Change
Mersa Matruh, Equatorial Guinea	25 Jul/12Z	500	+30.0	-30.0	0.0
		400	-13.1	No Change	No Change

4.2 Total Error Count. A less direct method of comparison is to simply count the total number of errors (not the number of *stations* with errors) detected by both algorithms. As discussed in Section 3.3, differences in the way errors are classified leads to difficulties in comparing the results. The negative heights encountered in the data rejected by NUAV is probably the biggest problem. These errors were not checked manually, so there is certainly the possibility that a few of the corrections are bad.

Table 10 shows the CQCHT results for the 2 months studied. The total number of errors in 121 time periods (00Z and 12Z; 62 in July and 58 in November) and the average number of errors in each period are grouped by height, temperature, and pressure. Tables A-1 and A-2 in the Appendix show this information for July and November separately. Most errors occur in height values (about 85 each period), with a relatively small number of pressure errors (about 6 each period). An average of 80.6 corrections and 62.7 error detections are made each period by CQCHT.

Table 10. CQCHT error summary (July and November 1992).

	Number of errors			All	Average each period			All
	Height	Temp	Press		Height	Temp	Press	
Corrections	5,662	3,475	530	9,667	47.2	29.0	4.4	80.6
Data bad, no corrections.	4,559	2,800	170	7,529	38.0	23.3	1.4	62.7
Total errors	10,221	6,275	700	17,196	85.2	52.3	5.8	143.3
Suspect, but OK	1,854	1,449	----	3,303	15.5	12.0	12.0	27.5

Table 11. NUAV error summary (July and November 1992).

	Number of errors			All	Average each period			All
	Height	Temp	Press		Height	Temp	Press	
Corrections	1,982	4,738	128	6,848	16.4	39.2	1.1	56.6
No Change	226	3,260	0	3,486	1.9	26.9	0	28.8
Height negative	2,107	----	----	2,107	17.4	----	----	17.4
Old value missing	9	0	0	9	0.1	0	0	0.1

Table 11 shows the total number of errors corrected by NUAV during November (59 periods) and July (62 periods) 1992. Also shown are cases with negative height values (or less than -1,100 meters at 1,000 mb) and cases for which there was no change. Corrections of less than 2.0° C or 10 meters are categorized as "no change." Tables A-3 and A-4 in the Appendix show this information for July and November separately. The total number of corrections made by NUAV averages 24.0 fewer than CQCHT each period. Although CQCHT corrects many more height errors (47.2 versus 16.4) and pressure errors (4.4 versus 1.1) each period, NUAV leads in temperature corrections with 10.1 more corrections a period.

The counts in Table 11 must be viewed with caution because each one of the 6,848 corrections was not checked manually as was done in Section 4.1. Looking back at Table 7, we see that 52 errors were corrected by NUAV, not including undetermined and unnecessary corrections. Of this total, seven (13.5%) were corrected better by CQCHT and three (5.8%) were bad corrections. These calculations suggest that about 10 percent of the corrections in Table 11 could be of poor quality or wrong.

As mentioned previously, there is a possibility that many of the rejected negative heights (i.e., those declared to be in error) did not actually indicate a poor correction. Perhaps a good correction was made, but the faulty original value kept this fact from being discovered. A sample of 50 cases with rejected negative heights was compared to the original CQCHT values to see if NUAV actually made a correction or not. In this sample, 40 percent of the heights *were* corrected; in other words, the new value generated by NUAV was different than the original CQCHT value in 40 percent of the cases. In the remaining 60 percent,the new NUAV value was identical to the original CQCHT value, indicating that no change was made. Assuming these percentages are representative of all 2,107 values, the number of height corrections would be increased by 843 to 2,825 or 23.3 per period. The average number of total corrections per period would increase to 63.6.

Table 12. Number of stations with errors (July and November 1992).

Region (block #s)	Stations Checked		Errors Detected		Error Percentage	
	CQCHT	NUAV	CQCHT	NUAV	CQCHT	NUAV
Europe (01-17)	10,930	10,340	407	832	3.72	8.05
Former USSR (20-38)	17,778	17,631	1,501	1,488	8.44	8.44
Asia (40-41, 44-48)	7,643	7,616	871	637	11.40	8.36
India (42 and 43)	3,256	3,384	1,400	201	43.00	5.94
China (50-59)	14,546	14,543	1,440	19	9.90	0.13
Africa (60-68)	3,856	3,891	625	325	16.21	8.35
N. America (70-74)	14,566	14,439	285	369	1.96	2.56
Cen. America (76, 78)	2,039	2,069	201	212	9.86	10.25
S.America, Antarctica (80-89)	3,005	3,151	532	364	17.70	11.55
Australia and Pacific (91-98)	6,595	6,134	626	416	8.07	6.78
TOTALS	84,214	83,198	7,888	4,863	9.37	5.85

4.3 Stations with Errors. The last method used to compare NUAV and CQCHT is to compare the number of *stations* with errors. A RAOB with height errors at every level from 850 to 100 mb and a few temperature errors as well, is only counted as *one* error, rather than nine. Table 12 shows the number of stations with errors in the months of July and November combined. Also shown are the number of stations checked and the percentage of stations with errors (Tables A-5 and A-6 in the Appendix show the same information separately for July and November). The number of stations checked is provided in the CQCHT summary generated by NMC every month. The numbers used for NUAV are actually the number of complete soundings (up to 100 mb) going into the DATSAV2 database. More complete data, such as the number of part A and C sections checked, is not available. For these reasons, consider the number of stations checked by NUAV and shown in Table 12 approximate. In most cases, however, the values for NUAV and CQCHT agree quite closely.

The most dramatic difference between the two algorithms occurs in the China data. Although the number of Chinese stations checked is nearly identical, NUAV finds only a fraction of the errors detected by CQCHT. More observational or measurement errors occur in data from Third World nations due to equipment problems; this type of error is missed by the hydrostatic check. CQCHT is able to detect more of these errors with its additional checks. This fact may explain a portion of the difference, but hydrostatic errors are still the most common in China; more than 19 of these almost certainly occurred. It's hard to believe that North America had an error percentage rate 20 times higher than China, especially in light of the relative agreement among the algorithms in Asia, the former USSR, North America, Central America, and Australia. Possibly some aspect of NUAV prevents all the data from being checked, although there is no direct evidence for this. China produces relatively reliable upper-air data compared to India where, according to CQCHT, an astounding 43 percent of the soundings have errors.

CQCHT results have found that most regions of the world have fewer observational errors than errors detected by the hydrostatic check (Morone et al., 1992). The exception is India, where more than twice as many errors are observational. This fact may help explain the huge difference in errors detected in India by CQCHT and NUAV, but the same problem that affects the data from China may play a role. It certainly seems unlikely that Europe, with its mostly automated RAOB network, has a significantly higher error rate than India's.

It is only among the high-quality soundings of North America and Europe that NUAV detects a much higher percentage of errors than CQCHT. As has been shown, the poor corrections and unnecessary corrections in the NUAV data probably raise the error numbers. Although some inaccuracies in the counts of stations processed surely exist, it's probable that the higher worldwide percentages obtained by CQCHT actually reflect the presence of additional statistical checks in the NMC algorithm.

5. CONCLUSIONS.

This study shows NMC's CQCHT to be a better QC algorithm than AFGWC's NUAV.

NUAV, which became operational on 22 December 1986, relies primarily on the hydrostatic check to detect errors. The hydrostatic equation provides a very powerful constraint on heights and temperatures, but it cannot be used to detect observational errors—those that occur before the data is processed at the reporting station. If a broken sensor gives temperature readings that are off by a few degrees, these readings will be used in the hydrostatic equation to compute the mandatory heights, thereby giving incorrect height values. When this data is quality-controlled, the hydrostatic check will not find an error, and the errors may be too small to be detected by NUAV's gross error check.

In contrast, CQCHT uses quantitative increment, horizontal, and vertical checks to detect errors. CQCHT became operational in November 1991 and employs the latest techniques in automated QC. NMC produces monthly summaries of QC results that are continually monitored for any CQCHT problems or chronic data problems at any one station. NUAV essentially employs the same techniques used by the previous generation of NMC QC algorithms (CHQC in 1989).

A direct comparison of 50 randomly selected stations found CQCHT alone detected 48.9 percent of the total errors. Both algorithms detected 25.6 percent of the errors, while NUAV alone detected 25.5 percent. Of the errors found only by NUAV, 33.3 percent were either bad or unnecessary. When both algorithms corrected the same observation, the CQCHT correction was better 19.4 percent of the time, with comparable corrections being made on the rest of the observations. Although the categories used in this section were determined subjectively, and the lack of available NUAV data made categorizing NUAV corrections difficult, the amount of quantitative evidence provided with each CQCHT correction made confident categorizations possible.

A comparison of the total number of errors corrected by each algorithm found that CQCHT made an average of 24 more corrections each period than NUAV (2,819 more corrections) during the 2 months studied. There were uncertainties in this comparison, however, because the large number of rejected height values that are negative make these cases difficult to classify. Using estimates suggesting that about 40 percent of these cases are actually corrections still leaves NUAV 1,976 corrections short of CQCHT's performance over a 2-month period. In addition to corrections, CQCHT also detects 7,529 uncorrectable errors during the study period. These errors are either rejected or assimilated with reduced weight.

NUAV detected 3,025 fewer *stations* with errors during the study period. It should be noted that the error counts made by NUAV for China and India are dramatically lower than those made by CQCHT. It is possible that a NUAV problem peculiar to stations in China and India leads to the large difference in these areas.

While the evidence supporting CQCHT as the more advanced QC algorithm is strong, this study does not address other factors which must also be considered before deciding to receive QC data from NMC. For example, will differing data cutoff times allow all the data of interest to AFGWC to get into the database? The costs of updating NUAV, if that option were pursued, may be much greater than those associated with receiving CQCHT data. The degree of monitoring performed on each algorithm is another important consideration. Further discussions with scientists at NMC are required before these issues can be resolved completely.

APPENDIX

Comparison Tables (CQCHT versus NUAV) July and November

Table A-1. CQCHT error summary for July 1992.

	Number of errors			All	Average each period			All
	Height	Temp	Press		Height	Temp	Press	
Corrections	2,817	1,539	264	4,620	45.4	24.8	4.3	74.5
Data bad, no corrections	2,118	1,241	80	3,439	34.2	20.0	1.3	55.5
Total errors	4,935	2,780	344	8,059	79.6	44.8	5.5	130.0
Suspect, but OK	836	695	----	1,531	13.5	11.2 --		24.7

Table A-2. NUAV error summary for July 1992.

	Number of errors			All	Average each period			All
	Height	Temp	Press		Height	Temp	Press	
Corrections	1,015	2,259	97	3,371	16.4	36.4	1.6	54.4
No Change	113	1,585	0	1,698	1.8	25.6	0	27.4
Height negative	1,045	----	----	1,045	16.9	----	----	16.9
Old value missing	5	0	0	5	0.1	0	0	0.1

Table A-3. CQCHT error summary for November 1992.

	Number of errors			All	Average each period			All
	Height	Temp	Press		Height	Temp	Press	
Corrections	2,845	1,936	266	5,047	49.1	33.4	.6	87.0
Data bad, no cor.	2,441	1,559	90	4,090	42.1	26.9	1.6	70.5
Total errors	5,286	3,495	356	9,137	91.1	60.3	6.1	157.5
Suspect, but OK	1,018	754	----	1,772	17.6	13.0	----	30.6

Table A-4 NUAV error summary for November 1992.

	Number of errors			All	Average each period			All
	Height	Temp	Press		Height	Temp	Press	
Corrections	967	2,479	31	3,477	16.4	42.0	0.5	58.9
No Change	113	1,675	0	1,788	1.9	28.4	0	30.3
Height negative	1062	----	----	1,062	18.0	----	----	18.0
Old value missing	4	0	0	4	0.1	0	0	0.1

Table A-5 Number of Stations with errors in July. Figures are given in total stations and percentage of stations with errors in the regions shown.

Region (block #s)	Stations		Errors		Error Percentage	
	CQCHT	NUAV	CQCHT	NUAV	CQCHT	NUAV
Europe (01-17)	5,583	5,440	193	400	3.46	7.35
Former USSR (20-38)	8,626	8,807	663	784	7.69	8.90
Asia (40-41, 44-48)	3,775	3,819	428	342	11.34	8.96
India (42 and 43)	1,638	1,727	745	125	45.48	7.24
China (50-59)	7,476	7,389	745	9	9.97	0.12
Africa (60-68)	2,077	2,113	343	185	16.51	8.76
North America (70-74)	7,371	7,285	155	179	2.10	2.46
Central America (76, 78)	1,075	1,091	108	120	10.00	11.00
South America, Antarctica (80-89)	1,453	1,554	273	180	18.79	11.58
Australia and Pacific (91-98)	3,062	3,019	180	119	5.88	3.94
TOTAL	42,136	42,244	3,833	2,443	9.10	5.78

Table A-6 Number of Stations with errors in November. Figures are given in total stations and percentage of stations with errors in the regions shown.

Region (block #s)	Stations		Errors		Error Percentage	
	CQCHT	NUAV	CQCHT	NUAV	CQCHT	NUAV
Europe (01-17)	5,347	4,900	214	432	4.00	8.82
Former USSR (20-38)	9,152	8,824	838	704	9.16	.98
Asia (40-41, 44-48)	3,868	3,797	443	295	11.45	7.77
India (42 and 43)	1,618	1,657	655	76	40.48	4.59
China (50-59)	7,070	5,781	695	10	9.83	0.17
Africa (60-68)	1,779	1,778	282	140	15.85	7.87
North America (70-74)	7,195	7,154	130	190	1.81	2.66
Central America (76, 78)	964	978	93	92	9.65	9.41
South America, Antarctica (80-89)	1,552	1,597	259	184	16.69	11.52
Australia and Pacific (91-98)	3,533	3,115	446	297	12.62	9.53
TOTAL	42,078	40,954	4,057	2,420	9.64	5.91

BIBLIOGRAPHY

Anderson, V., and L.W. Smart, *Methods in Modern Climatology*, Harvard University Press, Cambridge, MA, 1970.

Ahnert, P.R., "Precision and Comparability of National Weather Service Upper Air Measurements," *Preprints, Seventh Symposium on Meteorological Observations and Instrumentation*, 221 - 226, 1991.

Collins, W.G., "Complex Quality Control of Rawinsonde Heights and Temperatures at the National Meteorological Center," *Preprints, Ninth Conference on Numerical Weather Prediction*, 15 - 18, 1991.

Collins, W.,G. and L.S. Gandin, "Comprehensive Hydrostatic Quality Control at the National Meteorological Center, *Mon. Wea. Rev.*, **118**, 2754 - 2767, 1990.

Gandin, L.S., "Complex Quality Control of Meteorological Observations," *Mon. Wea. Rev.*, **116**, 1138-1156, 1988.

Gandin, L.S. and W.G. Collins, "Complex Quality Control and Decision Making Algorithms," *Preprints, Tenth Conference on Numerical Weather Prediction*, 299 - 304, 1992.

Morone, L.L., W.G. Collins and L.S. Gandin, "Quasi-Operational Monitoring of the NMC Complex Quality Control Performance," *Preprints, Tenth Conference on Numerical Weather Prediction*, 305 - 309, 1992.

Zamiska, P.A., *AFGWC's Upper Air Validator System*, AFGWC/TN-90/001, February 1990.

DISTRIBUTION

DR WILLIAM COLLINS, NAT'L METEOROLOGICAL CTR, W/NM2 WWB, ROOM 204, WASHINGTON DC 20233-5000 . . . 1
HQ USAF XOOOW RM 8D927 5054 AIR FORCE PENTAGON WASHINGTON DC 20330-5054 1
OSAF SS RM 4C1052 6560 AIR FORCE PENTAGON WASHINGTON DC 20330-6560 1
USTC J3 J4-OW BLDG 1900 508 SCOTT DR SCOTT AFB IL 62225-5357 1
AWS DO 102 W LOSEY ST BLDG 1521 SCOTT AFB IL 62225-5206 1
AWS XTX 102 W LOSEY ST BLDG 1521 SCOTT AFB IL 62225-5206 1
DET 5 HQ AWS WALL STUDIO BLDG 0902 709 H ST STE 201 KEESLER AFB MS 39534-2447 1
OL-B HQ AWS (ESC AVD) 20 SCHILLING CIRCLE HANSCOM AFB MA 01731-2816 1
OL-F HQ AWS SMC CIA PO BOX 92960 2401 EL SEGUNDO BLVD LOS ANGELES CA 90009-2960 1
OL-K HQ AWS NEXRAD OPS SUPPORT FACILITY 3200 MARSHALL DR STE 100 NORMAN OK 73072-8028 1
OL-N HQ AWS C O ARL (AMSRL-BE-W) BLDG 1646 RM 24 WHITE SANDS MISSILE RNG NM 88002-5501 1
HQ AFGWC DO MBB39 106 PEACEKEEPER DR STE 2N3 OFFUTT AFB NE 68113-4039 1
HQ AFGWC SY MBB39 106 PEACEKEEPER DR STE 2N3 OFFUTT AFB NE 68113-4039 1
AFSFC DOM 715 KEPLER AVE STE 60 FALCON AFB CO 80912-7160 1
OL-A AFSFC RE SE2 325 BROADWAY BOULDER CO 80303-3328 1
USAFETAC 859 BUCHANAN ST SCOTT AFB IL 62225-5116 1
USSTRATCOM J3615 901 SAC BLVD STE 1F14 OFFUTT AFB NE 68113-6700 1
USCENTCOM CCJ3-W BLDG 540 MACDILL BLVD MACDILL AFB FL 33608-7001 1
USSOCCENT SOCJ2-SWO 7115 S BOUNDARY BLVD MACDILL AFB FL 33621-5101 1
HQ 1ST WEAG WSOT BLDG 130 ANDERSON WAY FT MCPHERSON GA 30300-5000 1
AMC XOW 402 SCOTT DR RM 132 SCOTT AFB IL 62225-5363 1
HQ AFSPACECOM DOGW 150 VANDENBERG ST STE 1105 PETERSON AFB CO 80914-4200 1
AFMC DOW 4225 LOGISTICS AVE STE 2 WRIGHT PATTERSON AFB OH 45433-5714 1
FASTC TAW 4115 HEBBLE CREEK RD STE 33 WRIGHT-PATTERSON AFB OH 45433-5637 1
AFIT CIR WRIGHT-PATTERSON AFB OH 45433-6583 1
AFIT ENP 2950 P ST WRIGHT PATTERSON AFB OH 45433-7765 1
WRDC WE BLDG 22 WRIGHT-PATTERSON AFB OH 45433-6543 1
645 WS DO 5291 SKEEL AVE STE 1 WRIGHT-PATTERSON AFB OH 45433-5231 1
UTTR WE HILL AFB UT 84056-5000 1
AFOTEC WE KIRTLAND AFB NM 87117-7001 1
ESMC WE PATRICK AFB FL 32925-5000 1
ESC WE 5 EGLIN ST HANSCOM AFB MA 01731-2122 1
PL GP ATTN DR HAROLD ROTH 29 RANDOLPH RD HANSCOM AFB MA 01731-3010 1
PL TSML 5 WRIGHT ST HANSCOM AFB MA 017313004 1
PL WE 3350 ABERDEEN KIRTLAND AFB NM 87117-5987 1
AFCESA WE TYNDALL AFB FL 32403-5000 1
AFESC RDXT BLDG 1120 STOP 21 TYNDALL AFB FL 32403-5000 1
46 TG WE HOLLOMAN AFB NM 88330-5000 1
OL-A AFCOS SITE R FORT RITCHIE MD 21719-5010 1
USAFALCENT RA POPE AFB NC 28308-5000 1
CCSO FL TINKER AFB OK 73145-6340 1
AFOSR NL BOLLING AFB DC 20332-5000 1
AL OEBE 2402 EAST DRIVE BROOKS AFB TX 78235-5114 1
AETC XOSW 1F ST STE 2 RANDOLPH AFB TX 78150-4325 1
5 WS (PACAF) UNIT 15173 APO AP 96205-0108 1
PACAF DOW BLDG 1102 25 E ST STE I232 HICKAM AFB HI 96853-5426 1
15 WS 800 HANGAR AVE HICKAM AFB HI 96853-5244 1
11 OPG WE 6900 9TH STE 205 ELMENDORF AFB AK 99506-5000 1
HQ NATO STAFF MET OFFICER LMS OPS APO AE 09724 1
USAFE DOOW UNIT 3050 BOX 15 APO AE 09094-5015 1
17AF WE UNIT 4065 APO AE 09136-5000 1
DET 1 86 WS UNIT 7890 APO AE 09126-7890 1
COMNAVOCEANCOM CODE N312 STENNIS SPACE CTR MS 39529-5000 1
COMNAVOCEANCOM CODE N332 STENNIS SPACE CTR MS 39529-5001 1
NAVOCEANO CODE N25131 ATTN BERNIE RAU BLDG 8100 RM 203D STENNIS SPACE CTR
MS 39522-5001 1
NAVOCEANO CODE 9220 STENNIS SPACE CTR MS 39529-5001 1
MAURY OCEANOGRAPHIC LIBRARY NAVAL OCEANOGRAPHY OFFICE STENNIS SPACE CTR
MS 39522-5001 1

NAVAL RESEARCH LABORATORY MONTEREY CA 93943-5006 1
NAVAL RESEARCH LABORATORY CODE 4323 WASHINGTON DC 20375 1
NAVAL POLAR OCEANOGRAPHY CTR 4301 SUITLAND ROAD FOB #4 WASHINGTON DC 20395-5108 1
NAVAL OCEANOGRAPHY COMMAND CTR PSC 819 BOX 13 FPO AE 09645-3200 1
ARMY TRAINING AND DOCTRINE COMMAND ATDO-IW (ATTN SWO) FT MONROE VA 23651-5000 1
JSOC WEATHER PO BOX 70239 FT BRAGG NC 28307-5000 1
ARMY RESEARCH LAB BATTLEFIELD ENVIRONMENT DIR ATTN AMSRL-BE-W WHITE SANDS
MISSILE RANGE NM 88002-5501 1
DIRECTOR USA-CETEC ATTN GL-AE FORT BELVOIR VA 22060-5546 1
US ARMY INTEL CTR AND FT HUACHUCA WEATHER SUPPORT TEAM ATTN ATZS-CDI-W FT HUACHUCA AZ
85613-6000 1
PL TSML RESEARCH LIBRARY HANSCOM AFB MA 01731-5000 1
ROME LAB TECH LIB FL2810 CDR W STE 262 RL SUL DOC LIB 26 ELECTRONICS PARKWAY
BLDG 106 GRIFFISS AFB NY 13441-4514 1
TECHNICAL LIBRARY DUGWAY PROVING GROUND DUGWAY UT 84022-5000 1
NOAA CENTRAL LIBRARY 1315 EAST-WEST HIGHWAY STE 2000 SILVER SPRING MD 20910 1
NOAA MASC LIBRARY MC5 325 BROADWAY BOULDER CO 80303-3328 1
NOAA NESDIS ATTN NANCY EVERSON E RA22 WORLD WEATHER BLDG RM 703
WASHINGTON DC 20233 1
NGDC NOAA ATTN: AF LIAISON OFFICER MAIL CODE E GC2 325 BROADWAY
BOULDER CO 80333-3328 1
NWS W OSD BLDG SSM C-2 EAST-WEST HWY SILVER SPRING MD 20910 1
NIST PUBS PRODUCTION RM A635 ADMIN BLDG GAITHERSBURG MD 20899 1
DTIC-FDAC CAMERON STATION ALEXANDRIA VA 22304-6145 1
AUL LSE BLDG 1405 600 CHENNAULT CIRCLE MAXWELL AFB AL 36112-6424 1
AWSTL 859 BUCHANAN ST SCOTT AFB IL 62225-5118 35